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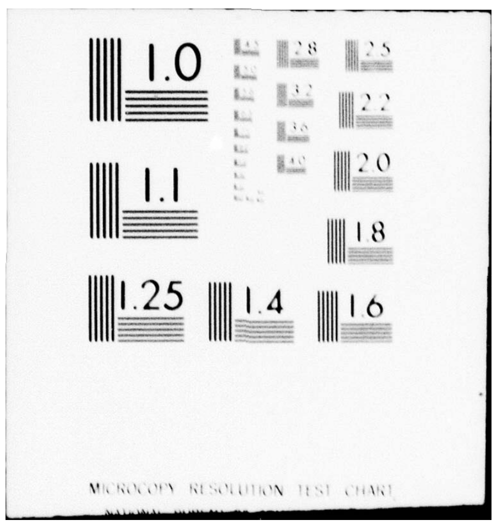
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INVERSE MEAN FREE PATH, STOPPING POWER, CSDA RANGE, AND STRAGGLING IN POLYSTYRENE FOR ELECTRONS OF ENERGY ≤10 keV

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Dr. R. Ritchie is the principal investigator for this contract. Dr. John N. Bradford (RADC/ESR) is the RADC Project Engineer.

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The interaction of electrons with solid polystyrene, -(C_8H_8)-, is described based on a model insulator theory to account for the response of the valence electrons, and carbon K-shell ionization cross sections derived from atomic, generalized oscillator strengths. Contributions to the inverse mean free path and energy loss due to these two excitation processes are tabulated for incident electrons with energies from 5 eV to 10 keV. Electron ranges in the continuous-slowing-down approximation and straggling are tabulated for electrons with energies from 15 eV to 10 keV.

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I. INTRODUCTION

A quantitative description of the interaction of electrons with solids over a wide range of energies is a subject of importance in a wide variety of basic and applied physical problems. Theoretical calculations of energy loss and range of electrons in many materials have formed the basis of at least two extensive tabulations.[1,2] Both of those tabulations are based on the Bethe theory of stopping power and are restricted to electron energies $\geq$ 10 keV. To complement these results we have employed several theoretical models to provide calculations of inverse mean free path, energy loss, csda range, and straggling for electrons with energies < 10 keV. Tables of these quantities are now available for the solids Al and Al_2O_3 (Reference 3); Si and SiO_2 (Reference 4); Ni, Cu, Ag, and Au (Reference 5); and Ge and GaAs (Reference 6). These tables should provide useful guides for interpretation of experimental data as well as input for calculations in applied areas.

The work presented here for the organic insulator polystyrene, $-(C_8H_8)-$, employs a model insulator theory[3,6,7] to describe the response of the valence band electrons. The states of the tightly bound K-shell electrons are assumed to retain a free-atom-like character so the excitation of these electrons to the continuum is described by cross sections derived from atomic, generalized oscillator strengths (GOS's).[8] In the following sections we describe the calculation of differential inverse mean free paths (DIMFP's) for interaction of an electron with the valence band or carbon K-shell electrons in the solid polystyrene and the derivation of inverse mean free path (IMFP) and energy loss from these DIMFP's.

Results are presented graphically for the IMFP and energy loss (or stopping power of the polystyrene) and in tabular form for the IMFP, stopping power, csda range, and straggling for electrons of energy from a few electron volts through 10 keV.

II. GENERAL FORMULATIONS

A charged particle passing through a solid interacts with a large number of electrons simultaneously, and it is thus appropriate to speak of a mean free path of the charged particle for energy transfer to the solid. Assuming the effect of the charged particle on the medium may be described in first Born approximation, the inverse mean free path, differential in momentum transfer $\hbar\vec{k}$, and energy transfer $\hbar\omega$, for a particle of velocity $\vec{v}$ is given by

$$\frac{d^2\mu}{dk\,d\omega} = \frac{2e^2}{\pi\hbar v}\,\frac{1}{k}\,\mathrm{Im}\left[\frac{-1}{\varepsilon(k,\omega)}\right], \qquad (1)$$

where $\varepsilon(k,\omega)$ is the dielectric response function of the solid.[9,10] We assume in this work that the solid is isotropic and homogeneous so that ε is a scalar function of k and ω.

For our calculations of inverse mean free path, stopping power, etc., it is sufficient to compute inverse mean free paths differential in energy transfer only. This differential inverse mean free path (DIMFP) for energy loss $\hbar\omega$ by an electron with energy $E = mv^2/2$ in the solid is given by

$$\tau(E,\hbar\omega) \equiv \frac{d\mu}{d(\hbar\omega)} = \frac{1}{\pi a_0 E} \int_{k_-}^{k_+} \frac{dk}{k} \, \mathrm{Im}\left[\frac{-1}{\varepsilon(k,\omega)}\right], \tag{2}$$

where $\hbar k_{\pm} \equiv \sqrt{2m}\,[\sqrt{E} \pm \sqrt{E - \hbar\omega}]$ and $a_0 \equiv \hbar^2/me^2$. This expression assumes that the energy-momentum relation for a swift electron in the solid does not differ appreciably from that of a free electron in vacuum.

Given $\varepsilon(k,\omega)$ for the solid, the quantities of interest here follow directly from $\tau(E,\hbar\omega)$. The inverse mean free path of the electron, μ, is given by integrating over allowed energy transfers as

$$\mu(E) = \int d(\hbar\omega) \; \tau(E,\hbar\omega). \tag{3}$$

The rate of energy loss of the electron, or the stopping power of the medium, is given by

$$S(E) \equiv -dE/dx = \int d(\hbar\omega) \; \hbar\omega \; \tau(E,\hbar\omega), \tag{4}$$

and the mean square energy loss per unit path length by

$$\Omega^2(E) \equiv \int d(\hbar\omega)(\hbar\omega)^2 \; \tau(E,\hbar\omega). \tag{5}$$

With these results we may calculate the range of an electron in the continuous-slowing-down approximation (csda range) by

$$R_o(E) = \int_{E_o}^{E} dE'/S(E') \tag{6}$$

and the mean square fluctuation in the range or "range straggling" will be calculated from Eqs. (4) and (5) as[11]

$$(R - R_o)^2_{AV} \equiv \int_{E_o}^{E} dE' \; \Omega^2(E')/[S(E')]^3 . \tag{7}$$

For our tabulations we take the lower limit in the integrations of Eqs. (6) and (7) as E_o = 10 eV.

III. DIMFP FOR THE VALENCE BAND

The model insulator theory used to derive the DIMFP for interaction of an electron with the valence band electrons has been described and employed in several previous calculations.[3,6,7] Instead of repeating the detailed formulae here, we present graphically some of the steps required to obtain the energy loss function, $Im[-1/\varepsilon(k,\omega)]$, which is the key ingredient in the calculation of the DIMFP.

The first step in applying the model insulator theory is to fix the adjustable parameters by fitting the theoretical expression for the imaginary part of the dielectric response function in the optical limit ($k \to o$) to experimentally determined values of this quantity. In Figure 1 we

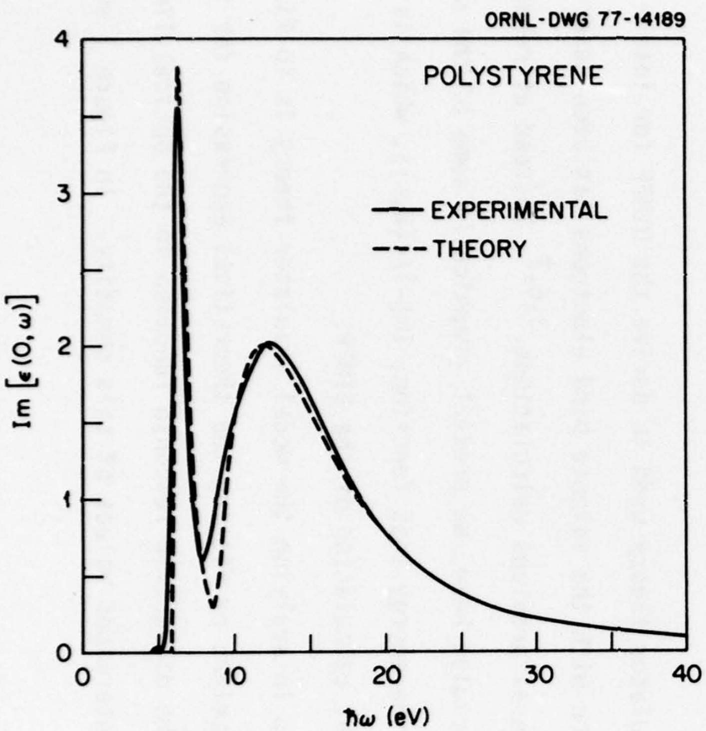

Fig.1 The imaginary part of the optical dielectric function for polystyrene as measured (solid line) and as calculated from a model insulator theory.

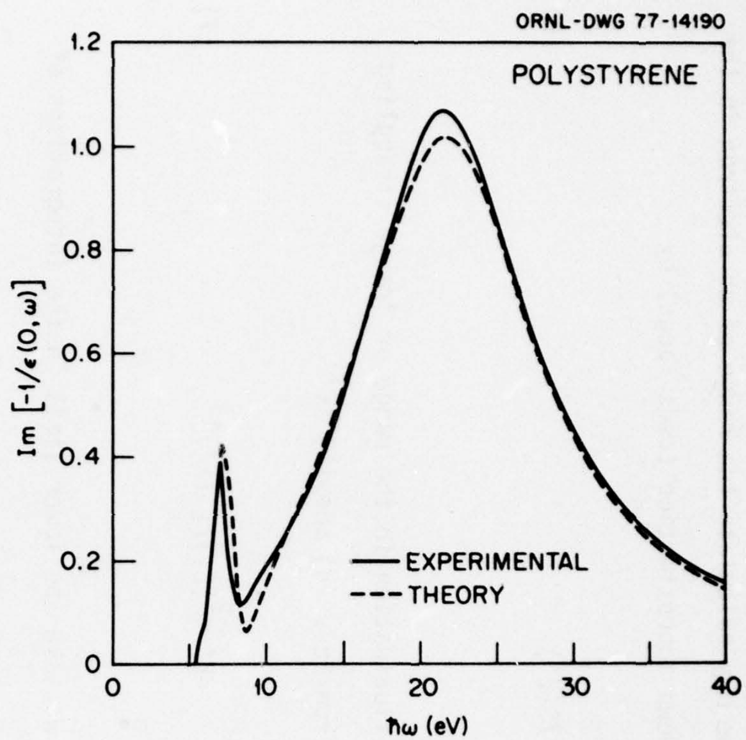

Fig. 2 The energy loss function (in the optical limit) for polystyrene as calculated from experimental data (solid curve) and from a model insulator theory (dashed curve).

show the results of the fit using experimental values obtained by Inagaki et al.[12] for polystyrene. The valence band is assumed to result from a combination of three ground state orbitals and the fit shown in Figure 1 gives the following set of parameters (as defined in References 3, 6, and 7):

i	αa_0	$\hbar\omega_{Bi}$(eV)	n_i
1	0.29	5.80	2.5
2	0.87	8.50	31.5
3	1.90	25.0	7.5

where n_i is the number of valence electrons per monomeric unit accounted for by each level and $\beta = 1/2$ for each of the three levels. Note that we account for 41.5 electrons per monomeric unit in the valence band instead of the expected 40. This redistribution of electron numbers between the core and valence electrons is due to oscillator strength coupling between the core and valence levels.[12] Since there are 56 electrons per monomeric unit, we will account for an effective number of 14.5 carbon K-shell electrons (or 7.25 K shells) per monomeric unit in our calculations of DIMFP's in Section IV. The density of polystyrene for these calculations is taken to be 1.05 g/cm^3. With the molecular weight of 104.14 g/mole for polystyrene, this density corresponds to 6.07×10^{-3} monomeric units/Å^3.

As a further comparison we show in Figure 2 the energy loss function in the optical limit calculated from the experimental data[12] and calculated from the model insulator theory using the parameters determined above. Quite reasonable agreement is seen in both Figures 1 and 2.

The extension of the energy loss function to arbitrary values of momentum transfer as determined by the model insulator theory is illustrated in Figure 3 where energy and momentum transfer are given in atomic units.

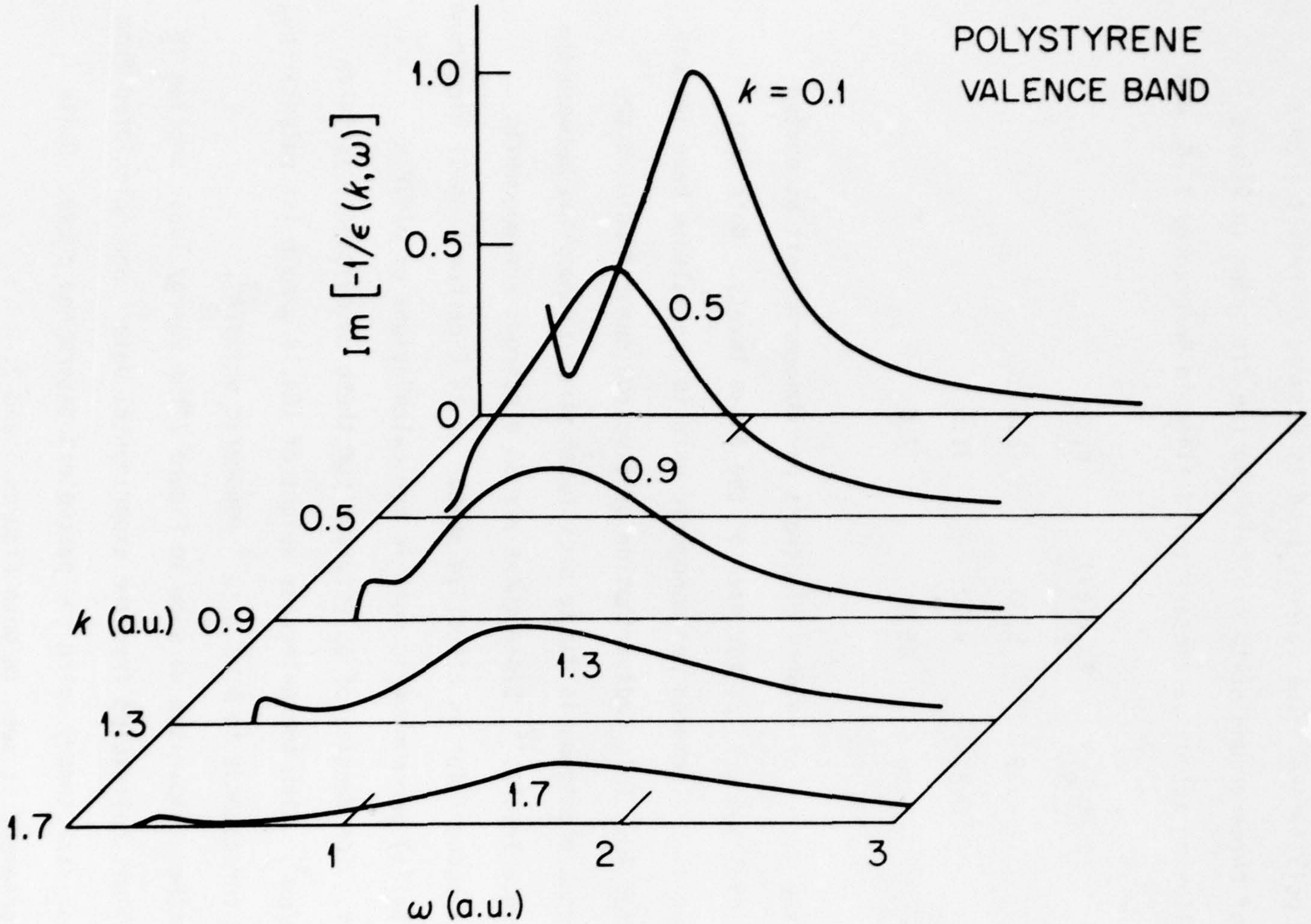

Fig. 3 Extension of the energy loss function into the momentum transfer plane as prescribed by a model insulator theory.

Calculations of DIMFP from Eq. (2) are illustrated in Figure 4 where we plot $E\tau$ as a function of energy transfer for several values of electron energy, with all quantities expressed in atomic units.

IV. DIMFP FOR CARBON K SHELL

From a general expression for the dielectric function of a homogeneous, isotropic system[13] we may show that for values of ω which correspond to ionization of a given inner shell in a solid that

$$\mathrm{Im}\,[-1/\varepsilon(k,\omega)] \approx \mathrm{Im}\,\varepsilon(k,\omega) \approx \frac{2\pi ne^2}{m\omega}\,\frac{df(k,\omega)}{d\omega}\,, \tag{8}$$

where $df/d\omega$ is the GOS and n is the number of those inner shells per unit volume in the solid. Equation (2) thus leads to

$$\tau(E,\hbar\omega) = \frac{8\pi a_o^2 n}{(E/R)\,(\hbar\omega/R)} \int_{k_-}^{k_+} \frac{dk}{k}\,\frac{df(k,\omega)}{d(\hbar\omega)}\,, \tag{9}$$

where $R = e^2/2a_o = 13.6$ eV.

Generalized oscillator strengths for ionization of electrons from the K shell of carbon have been calculated by McGuire.[8] These GOS values have been used in Eq. (9) to obtain the differential cross section $d\sigma/d(\hbar\omega) \equiv \tau/n$. Some typical results are shown in Figure 5 for several values of electron energy. The binding energy of the K-shell electrons in carbon is $\sim$ 282 eV. As discussed in Section III, we account for an effective 7.25 K shells per monomeric unit in calculating τ.

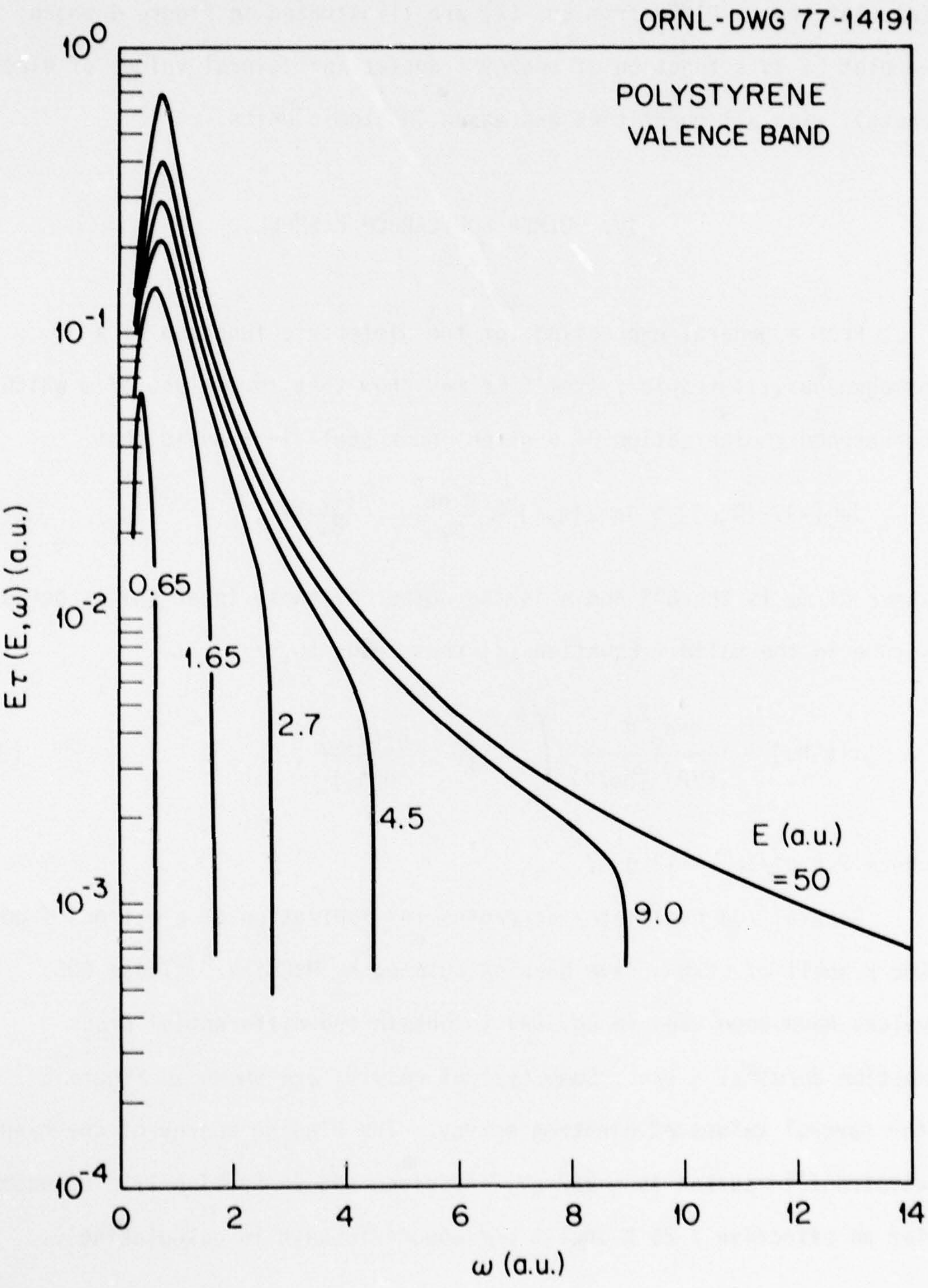

Fig. 4 DIMFP's for excitation of electrons from the valence band of polystyrene as determined by a model insulator theory for several values of incident electron energy E.

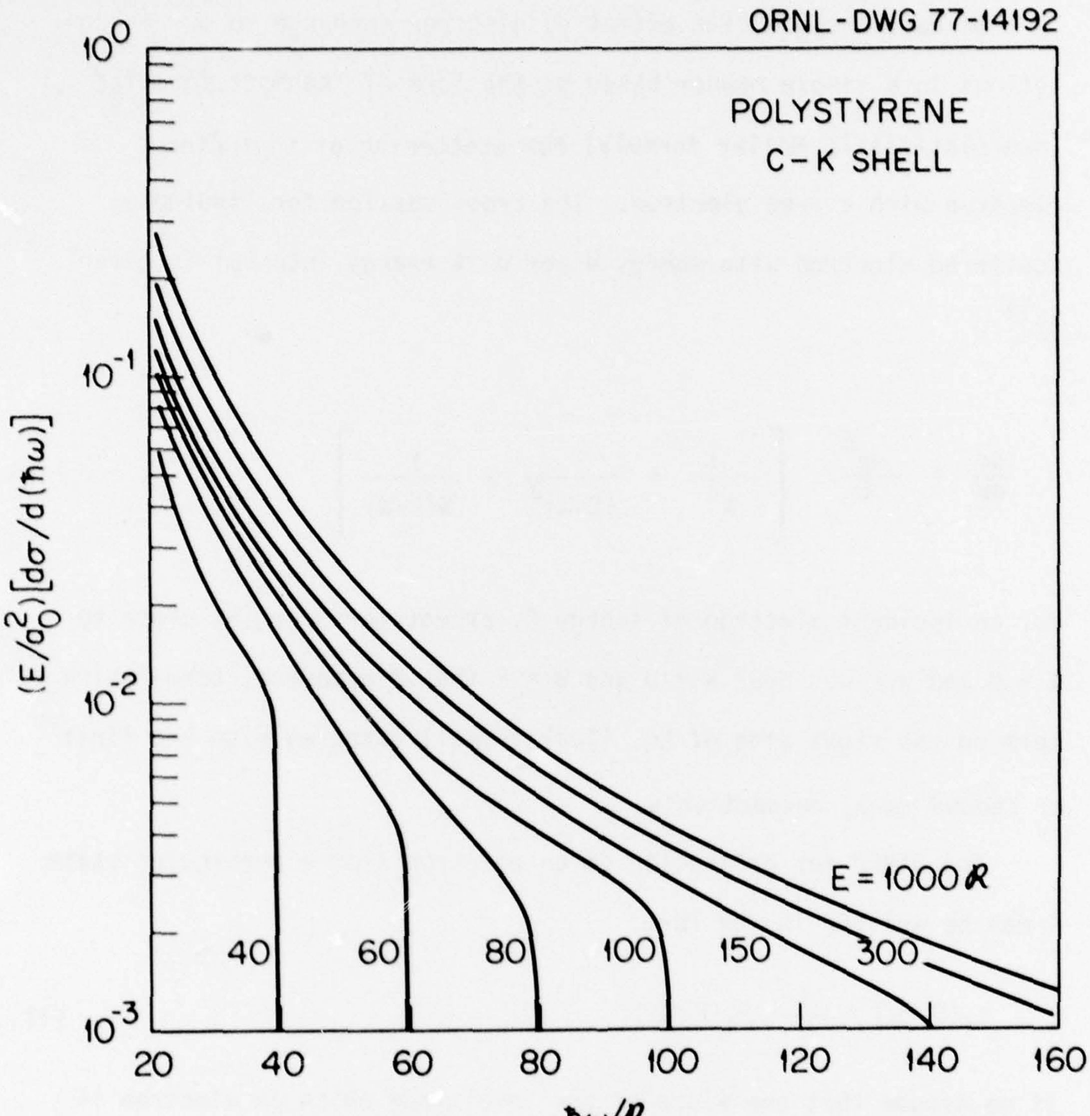

Fig. 5. Differential cross section for ionization of the K shell in carbon as derived from generalized oscillator strengths. R is the Rydberg energy $e^2/2a_0$ = 13.6 eV.

V. EXCHANGE CORRECTED DIMFP's AND FORMULAE FOR THE TABULATIONS

We have included the effect of electron exchange in our calculations in a simple manner based on the form of the Mott formula (nonrelativistic Møller formula) for scattering of an incident electron with a free electron. The cross section for finding a scattered electron with energy W per unit energy interval is given by[11]

$$\frac{d\Phi}{dW} = \frac{\pi e^4}{E} \left[\frac{1}{W^2} + \frac{1}{(E-W)^2} - \frac{1}{W(E-W)} \right] \qquad (10)$$

for an incident electron of energy E, except for energies close to $W = 0$ and $W = E$. Near $W = 0$ and $W = E$ the interference term (third term on the right side of Eq. (10)) is small compared with the first or second term, respectively.

The DIMFP for excitation of an electron from a particular state i may be written in the form

$$\tau_i(E,\hbar\omega) = \frac{1}{E} F_i(E,\hbar\omega). \qquad (11)$$

If we assume that the width of the level from which an electron is excited is quite narrow, we obtain from Eq. (11) the DIMFP for production of a secondary electron with energy E_s as

$$\tau_i^S(E,E_s) = \frac{1}{E} F_i(E,E_i^B+E_s) , \qquad (12)$$

where E_i^B is the binding energy of the i^{th} level (a positive quantity). The exchange corrected DIMFP is taken as

$$\tau_i^{exc}(E,\hbar\omega) = \frac{1}{E}\left\{F_i(E,\hbar\omega) + F_i(E,E+E_i^B-\hbar\omega) - \left[1 - \sqrt{E_i^B/E}\right]\left[F_i(E,\hbar\omega)F_i(E,E+E_i^B-\hbar\omega)\right]^{\frac{1}{2}}\right\} \quad . \qquad (13)$$

Since $E\tau_i \propto 1/(\hbar\omega)^2$ for large E and $\hbar\omega$, Eq. (13) reduces in this limit to the form given by Eq. (10). The factor $1 - \sqrt{E_i^B/E}$ reduces the contribution of the third term in Eq. (13) as $E \to E_i^B$. This form for the exchange corrected DIMFP has been used in our calculations for the inner shell and for the valence bands (since our model assumes the width of these levels to be quite narrow).

If we now define the more energetic of the two electrons after collision to be the primary and account for exchange through Eq. (13), Eq. (3) gives the contribution to the inverse mean free path due to excitation of an electron from the i^{th} level as

$$\mu_i(E) = \int_{E_i^B}^{(E+E_i^B)/2} d(\hbar\omega)\ \tau_i^{exc}(E,\hbar\omega). \qquad (14)$$

Similarly, for the stopping power and mean square energy loss per unit path length, we have from Eq. (4) and Eq. (5)

$$S_i(E) = \int_{E_i^B}^{(E+E_i^B)/2} d(\hbar\omega)\ \hbar\omega\ \tau_i^{exc}(E,\hbar\omega) \qquad (15)$$

and

$$\Omega_i^2(E) = \int_{E_i^B}^{(E+E_i^B)/2} d(\hbar\omega)\ (\hbar\omega)^2\ \tau_i^{exc}\ (E,\hbar\omega). \qquad (16)$$

For the remaining calculations we form the sums

$$S_{exc}(E) = \sum_i S_i\ (E) \qquad (17)$$

and

$$\Omega_{exc}^2(E) = \sum_i\ \Omega_i^2(E), \qquad (18)$$

where the index i includes the terms appropriate for a given solid, including exchange corrections as indicated above. The csda range is calculated from

$$R_o(E) = \int_{10eV}^{E} dE'/S_{exc}(E') \qquad (19)$$

corresponding to an electron slowing down in a continuous manner from an energy E to 10 eV. The mean square fluctuation in the csda range based on Eq. (7) is calculated as

$$(R-R_o)_{AV}^2\ = \int_{10eV}^{E} dE'\ \Omega_{exc}^2\ (E')/[S_{exc}(E')]^3. \qquad (20)$$

VI. RESULTS

Before presenting the tabulations for polystyrene, we discuss briefly the results for IMFP and stopping power. In Figure 6 the IMFP's are shown for interactions with the valence band (sum of contributions from the three levels, Section III) and with the carbon K shell. The K-shell contribution is quite small compared to the valence band contribution and amounts to $\lesssim$ 1% of the total IMFP in the energy range covered here. We have found no measurements of electron mean free paths in polystyrene for $E \leq 10$ keV. However, Swanson and Powell[14] performed characteristic energy loss measurements using 20 keV electrons on polystyrene films and determined mean free paths for the 7 eV and 21 eV losses. These losses correspond to the peaks seen in the energy loss function derived from optical data shown in Figure 2. They determine a mean free path λ, in Å, of 17,400 ± 5,500 for the 7 eV loss and 410 ± 80 for the 21 eV loss. If we assume these represent the dominant inelastic loss processes, then the total mean free path ($1/\lambda_{TOTAL} \equiv 1/\lambda_{7eV} + 1/\lambda_{21eV}$) is 400 Å (± ~ 20%) at 20 keV. Extrapolating our IMFP values to 20 keV yields $\mu \approx 2.5 \times 10^{-3}$ Å^{-1} or $\lambda = 1/\mu = 400$ Å in excellent agreement, possibly fortuitous, with the experimental result.

In Figure 7 we show the contributions to the stopping power of polystyrene for electrons. Also shown is the stopping power derived from Bethe-Bloch theory[1,2] for $E \geq 10$ keV. At 10 keV, the Bethe-Bloch result is $S = 0.237$ eV/Å for polystyrene of density $\rho = 1.05$ g/cm^3. Our value for $S = S$ (valence) + S (K-shell) is $S = 0.238$ eV/Å which

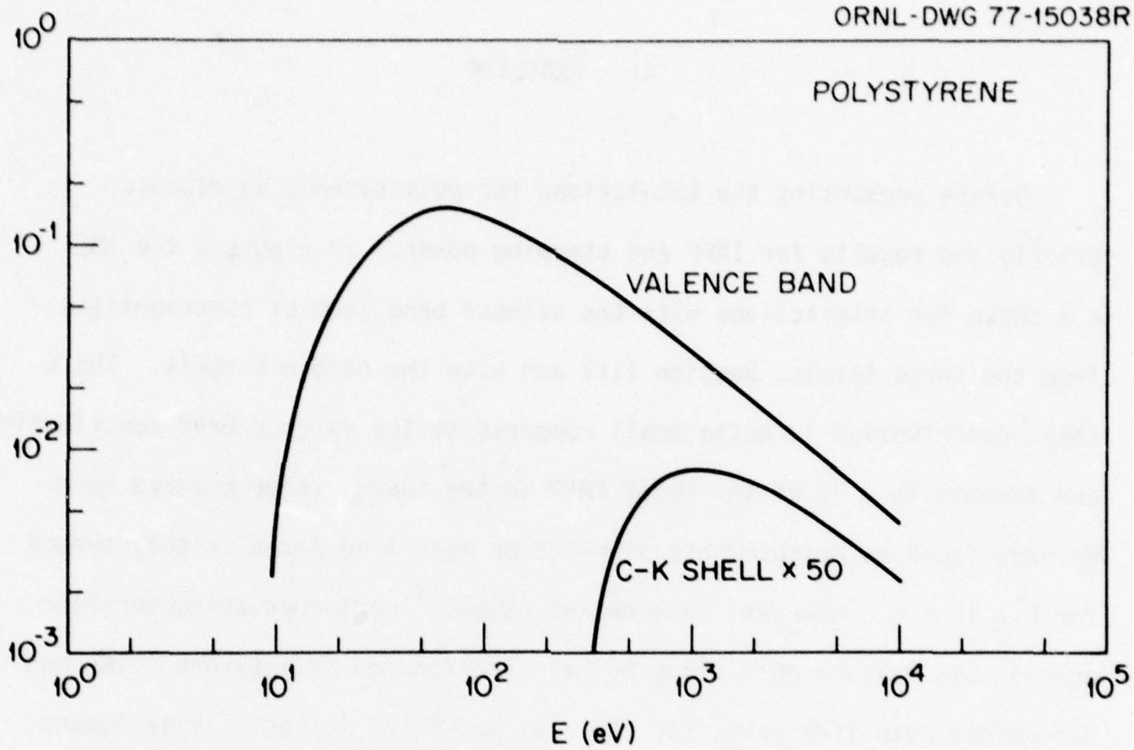

Fig. 6. IMFP for inelastic interaction of an electron of energy E with the valence-band electrons and K-shell electrons in polystyrene.

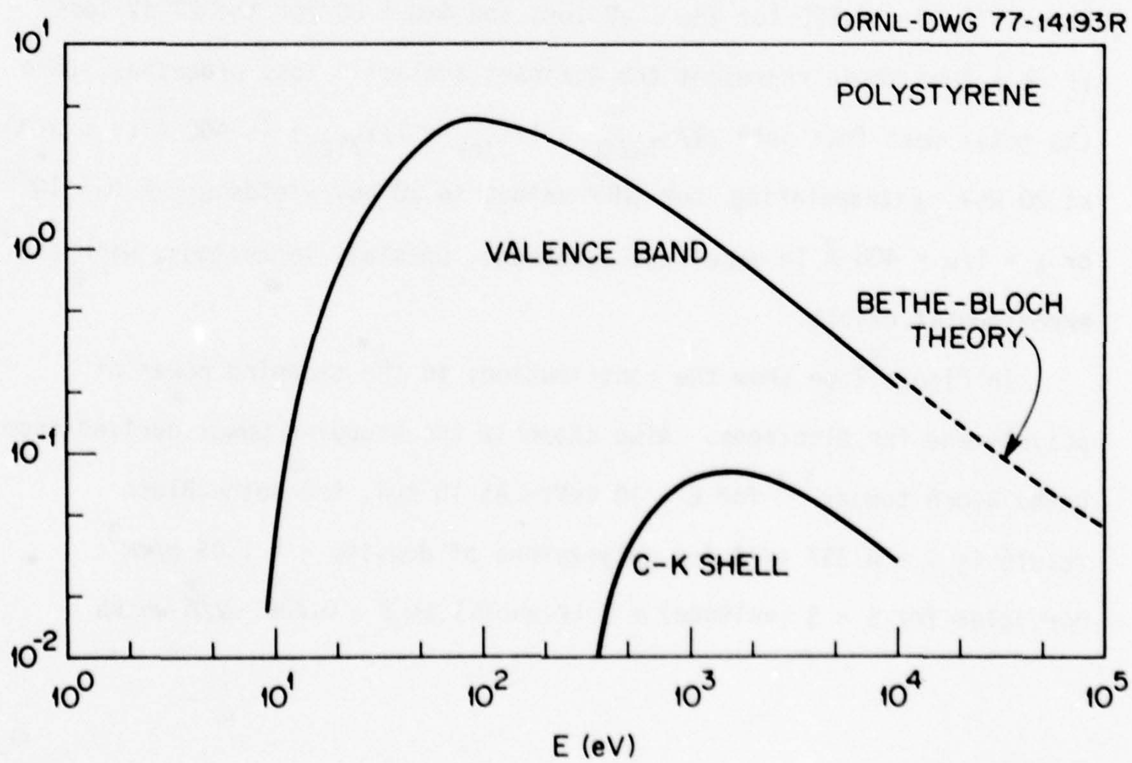

Fig. 7. Contributions from valence-band electrons and K-shell electrons to the stopping power of polystyrene for an electron of energy E.

agrees remarkably well with the previously tabulated results[1,2] at this energy. Our tabulated results for μ, S, range, and straggling are presented in Section VIII.

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VIII. TABLES

The results of the calculations for polystyrene, at a density of 1.05 g/cm^3, are given in the following tables:

Table 1 presents total inverse mean free path and contributions to IMFP due to interactions with valence band electrons or carbon K-shell electrons, Eq. (14), in units of $\mathring{A}^{-1}$ for incident electrons with energies 5 eV $\leq$ E $\leq$ 10 keV.

Table 2 presents total stopping power and contributions to the stopping power due to interactions with valence band electrons or carbon K-shell electrons, Eq. (15), in units of eV/$\mathring{A}$ for electron energies 5 eV $\leq$ E $\leq$ 10 keV.

Table 3 presents the csda range, Eq. (19), in units of $\mathring{A}$, the mean square energy loss, Eq. (16), in (eV)^2/$\mathring{A}$, the mean square range fluctuation, Eq. (20), in $\mathring{A}^2$, and the relative range straggling given by $[(R-R_0)^2_{AV}]^{1/2}/R_0$, for electron energies 15 eV $\leq$ E $\leq$ 10 keV.

TABLE 1

INVERSE MEAN FREE PATH OF ELECTRONS
IN POLYSTYRENE (DENSITY 1.05G/CM3)

ELECTRON ENERGY EV	INVERSE MFP A-1	INDIVIDUAL CONTRIBUTIONS TO IMFP IN UNITS OF A-1	
		VALENCE BAND	INNER SHELL (C-K SHELL)
5.000D 00	0.0	0.0	0.0
1.000D 01	4.590D-03	4.590D-03	0.0
1.500D 01	3.224D-02	3.224D-02	0.0
2.000D 01	5.731D-02	5.731D-02	0.0
2.500D 01	7.889D-02	7.889D-02	0.0
3.000D 01	9.858D-02	9.858D-02	0.0
3.500D 01	1.144D-01	1.144D-01	0.0
4.000D 01	1.273D-01	1.273D-01	0.0
4.500D 01	1.363D-01	1.363D-01	0.0
5.000D 01	1.428D-01	1.428D-01	0.0
5.500D 01	1.470D-01	1.470D-01	0.0
6.000D 01	1.491D-01	1.491D-01	0.0
6.500D 01	1.499D-01	1.499D-01	0.0
7.000D 01	1.499D-01	1.499D-01	0.0
7.500D 01	1.491D-01	1.491D-01	0.0
8.000D 01	1.477D-01	1.477D-01	0.0
8.500D 01	1.460D-01	1.460D-01	0.0
9.000D 01	1.440D-01	1.440D-01	0.0
9.500D 01	1.419D-01	1.419D-01	0.0
1.000D 02	1.392D-01	1.392D-01	0.0
1.500D 02	1.154D-01	1.154D-01	0.0
2.000D 02	9.778D-02	9.778D-02	0.0
2.500D 02	8.486D-02	8.486D-02	0.0
3.000D 02	7.465D-02	7.465D-02	1.615D-06
3.500D 02	6.706D-02	6.704D-02	2.370D-05
4.000D 02	6.112D-02	6.106D-02	5.032D-05
4.500D 02	5.598D-02	5.591D-02	7.457D-05
5.000D 02	5.172D-02	5.163D-02	9.203D-05
5.500D 02	4.816D-02	4.806D-02	1.063D-04
6.000D 02	4.512D-02	4.500D-02	1.136D-04
6.500D 02	4.248D-02	4.235D-02	1.326D-04
7.000D 02	4.015D-02	4.001D-02	1.402D-04
7.500D 02	3.807D-02	3.793D-02	1.451D-04
8.000D 02	3.620D-02	3.605D-02	1.486D-04
8.500D 02	3.450D-02	3.435D-02	1.513D-04
9.000D 02	3.298D-02	3.283D-02	1.533D-04
9.500D 02	3.160D-02	3.144D-02	1.548D-04
1.000D 03	3.034D-02	3.018D-02	1.583D-04
1.500D 03	2.188D-02	2.173D-02	1.492D-04
2.000D 03	1.729D-02	1.715D-02	1.352D-04
2.500D 03	1.437D-02	1.425D-02	1.211D-04
3.000D 03	1.234D-02	1.223D-02	1.087D-04
3.500D 03	1.084D-02	1.074D-02	9.861D-05
4.000D 03	9.686D-03	9.596D-03	8.991D-05
4.500D 03	8.766D-03	8.683D-03	8.267D-05
5.000D 03	8.015D-03	7.939D-03	7.660D-05
5.500D 03	7.390D-03	7.319D-03	7.140D-05
6.000D 03	6.861D-03	6.794D-03	6.696D-05
6.500D 03	6.406D-03	6.343D-03	6.304D-05
7.000D 03	6.012D-03	5.952D-03	5.957D-05
7.500D 03	5.666D-03	5.609D-03	5.651D-05
8.000D 03	5.360D-03	5.306D-03	5.381D-05
8.500D 03	5.087D-03	5.035D-03	5.138D-05
9.000D 03	4.842D-03	4.793D-03	4.918D-05
9.500D 03	4.621D-03	4.574D-03	4.715D-05
1.000D 04	4.421D-03	4.375D-03	4.527D-05

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TABLE 2

STOPPING POWER OF POLYSTYRENE (DENSITY 1.05G/CM3)

ELECTRON ENERGY EV	STOPPING POWER EV/A	INDIVIDUAL CONTRIBUTIONS TO THE STOPPING POWER IN UNITS OF EV/A	
		VALENCE BAND	INNER SHELL
5.000D 00	0.0	0.0	0.0
1.000D 01	3.893D-02	3.893D-02	0.0
1.500D 01	3.369D-01	3.369D-01	0.0
2.000D 01	7.168D-01	7.168D-01	0.0
2.500D 01	1.156D 00	1.156D 00	0.0
3.000D 01	1.649D 00	1.649D 00	0.0
3.500D 01	2.125D 00	2.125D 00	0.0
4.000D 01	2.583D 00	2.583D 00	0.0
4.500D 01	2.955D 00	2.955D 00	0.0
5.000D 01	3.288D 00	3.288D 00	0.0
5.500D 01	3.545D 00	3.545D 00	0.0
6.000D 01	3.745D 00	3.745D 00	0.0
6.500D 01	3.901D 00	3.901D 00	0.0
7.000D 01	4.019D 00	4.019D 00	0.0
7.500D 01	4.111D 00	4.111D 00	0.0
8.000D 01	4.180D 00	4.180D 00	0.0
8.500D 01	4.226D 00	4.226D 00	0.0
9.000D 01	4.252D 00	4.252D 00	0.0
9.500D 01	4.260D 00	4.260D 00	0.0
1.000D 02	4.237D 00	4.237D 00	0.0
1.500D 02	3.876D 00	3.876D 00	0.0
2.000D 02	3.483D 00	3.483D 00	0.0
2.500D 02	3.145D 00	3.145D 00	0.0
3.000D 02	2.841D 00	2.840D 00	4.746D-04
3.500D 02	2.613D 00	2.606D 00	7.373D-03
4.000D 02	2.432D 00	2.416D 00	1.652D-02
4.500D 02	2.266D 00	2.240D 00	2.572D-02
5.000D 02	2.125D 00	2.093D 00	3.289D-02
5.500D 02	2.007D 00	1.968D 00	3.929D-02
6.000D 02	1.905D 00	1.860D 00	4.528D-02
6.500D 02	1.818D 00	1.765D 00	5.287D-02
7.000D 02	1.738D 00	1.681D 00	5.739D-02
7.500D 02	1.666D 00	1.605D 00	6.064D-02
8.000D 02	1.600D 00	1.536D 00	6.337D-02
8.500D 02	1.537D 00	1.471D 00	6.575D-02
9.000D 02	1.479D 00	1.411D 00	6.791D-02
9.500D 02	1.426D 00	1.356D 00	6.986D-02
1.000D 03	1.379D 00	1.306D 00	7.368D-02
1.500D 03	1.040D 00	9.626D-01	7.791D-02
2.000D 03	8.483D-01	7.709D-01	7.741D-02
2.500D 03	7.204D-01	6.471D-01	7.332D-02
3.000D 03	6.276D-01	5.599D-01	6.767D-02
3.500D 03	5.578D-01	4.949D-01	6.290D-02
4.000D 03	5.020D-01	4.444D-01	5.753D-02
4.500D 03	4.569D-01	4.040D-01	5.298D-02
5.000D 03	4.198D-01	3.707D-01	4.912D-02
5.500D 03	3.887D-01	3.429D-01	4.581D-02
6.000D 03	3.622D-01	3.193D-01	4.296D-02
6.500D 03	3.394D-01	2.989D-01	4.045D-02
7.000D 03	3.194D-01	2.812D-01	3.823D-02
7.500D 03	3.018D-01	2.656D-01	3.626D-02
8.000D 03	2.862D-01	2.517D-01	3.452D-02
8.500D 03	2.723D-01	2.393D-01	3.295D-02
9.000D 03	2.597D-01	2.282D-01	3.153D-02
9.500D 03	2.483D-01	2.181D-01	3.023D-02
1.000D 04	2.380D-01	2.090D-01	2.903D-02

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TABLE 3

CSDA RANGE AND STRAGGLING OF ELECTRONS IN POLYSTYRENE (DENSITY 1.05G/CM3)

ELECTRON ENERGY EV	CSDA RANGE (E TO 10EV) A	MEAN SQUARE ENERGY LOSS EV2/A	MEAN SQUARE RANGE FLUCTUATION A2	RELATIVE RANGE STRAGGLING
1.50D 01	4.264D 01	3.471D 00	5.662D 03	1.765D 00
2.00D 01	5.269D 01	9.109D 00	5.897D 03	1.457D 00
2.50D 01	5.816D 01	1.833D 01	5.983D 03	1.330D 00
3.00D 01	6.176D 01	3.041D 01	6.028D 03	1.257D 00
3.50D 01	6.442D 01	4.450D 01	6.056D 03	1.208D 00
4.00D 01	6.654D 01	5.985D 01	6.076D 03	1.171D 00
4.50D 01	6.835D 01	7.429D 01	6.091D 03	1.142D 00
5.00D 01	6.995D 01	8.894D 01	6.105D 03	1.117D 00
5.50D 01	7.141D 01	1.018D 02	6.117D 03	1.095D 00
6.00D 01	7.278D 01	1.134D 02	6.128D 03	1.076D 00
6.50D 01	7.409D 01	1.239D 02	6.138D 03	1.057D 00
7.00D 01	7.535D 01	1.333D 02	6.149D 03	1.041D 00
7.50D 01	7.658D 01	1.424D 02	6.159D 03	1.025D 00
8.00D 01	7.779D 01	1.513D 02	6.169D 03	1.010D 00
8.50D 01	7.898D 01	1.587D 02	6.180D 03	9.954D-01
9.00D 01	8.015D 01	1.648D 02	6.190D 03	9.816D-01
9.50D 01	8.133D 01	1.699D 02	6.201D 03	9.683D-01
1.00D 02	8.251D 01	1.732D 02	6.212D 03	9.553D-01
1.50D 02	9.483D 01	1.950D 02	6.352D 03	8.404D-01
2.00D 02	1.085D 02	2.054D 02	6.555D 03	7.465D-01
2.50D 02	1.236D 02	2.098D 02	6.843D 03	6.695D-01
3.00D 02	1.403D 02	2.102D 02	7.239D 03	6.064D-01
3.50D 02	1.587D 02	2.122D 02	7.764D 03	5.552D-01
4.00D 02	1.785D 02	2.150D 02	8.432D 03	5.143D-01
4.50D 02	1.998D 02	2.175D 02	9.271D 03	4.818D-01
5.00D 02	2.226D 02	2.193D 02	1.031D 04	4.560D-01
5.50D 02	2.469D 02	2.210D 02	1.156D 04	4.355D-01
6.00D 02	2.724D 02	2.229D 02	1.305D 04	4.193D-01
6.50D 02	2.993D 02	2.259D 02	1.479D 04	4.063D-01
7.00D 02	3.275D 02	2.275D 02	1.681D 04	3.960D-01
7.50D 02	3.568D 02	2.286D 02	1.913D 04	3.876D-01
8.00D 02	3.875D 02	2.300D 02	2.177D 04	3.808D-01
8.50D 02	4.194D 02	2.310D 02	2.476D 04	3.752D-01
9.00D 02	4.525D 02	2.318D 02	2.814D 04	3.707D-01
9.50D 02	4.870D 02	2.331D 02	3.194D 04	3.670D-01
1.00D 03	5.226D 02	2.342D 02	3.618D 04	3.639D-01
1.50D 03	9.454D 02	2.403D 02	1.096D 05	3.502D-01
2.00D 03	1.484D 03	2.444D 02	2.626D 05	3.454D-01
2.50D 03	2.127D 03	2.452D 02	5.253D 05	3.408D-01
3.00D 03	2.873D 03	2.422D 02	9.327D 05	3.361D-01
3.50D 03	3.721D 03	2.385D 02	1.519D 06	3.313D-01
4.00D 03	4.667D 03	2.344D 02	2.323D 06	3.266D-01
4.50D 03	5.713D 03	2.295D 02	3.386D 06	3.221D-01
5.00D 03	6.856D 03	2.253D 02	4.746D 06	3.178D-01
5.50D 03	8.095D 03	2.217D 02	6.447D 06	3.137D-01
6.00D 03	9.428D 03	2.187D 02	8.538D 06	3.099D-01
6.50D 03	1.086D 04	2.160D 02	1.107D 07	3.065D-01
7.00D 03	1.237D 04	2.137D 02	1.408D 07	3.033D-01
7.50D 03	1.399D 04	2.116D 02	1.764D 07	3.003D-01
8.00D 03	1.569D 04	2.098D 02	2.180D 07	2.976D-01
8.50D 03	1.748D 04	2.081D 02	2.661D 07	2.951D-01
9.00D 03	1.936D 04	2.067D 02	3.213D 07	2.928D-01
9.50D 03	2.133D 04	2.053D 02	3.843D 07	2.906D-01
1.00D 04	2.339D 04	2.041D 02	4.556D 07	2.886D-01

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